

文章编号: 1000-0550(2000)01-0119-08

Quartz Cement in Middle Jurassic Reservoir Sandstones in North Sea A Review. Part II: Duration and Silica Sources

Shao-nan Zhang¹ Knut Bjørlykke²

¹ (Chengdu University of Technology Chengdu 610059)

² (Department of Geology Box 1047 University of Oslo 0316 Oslo 3 Norway)

Abstract The timing and duration of quartz cementation in sandstones have been mainly inferred from diagenetic texture relationship between pore filling minerals, fluid inclusions and isotopic data. Fluid inclusion temperatures from North Sea reservoir sandstones indicate that most of the quartz cement forms at temperature exceeding 90°C and is continually proceeding after oil emplacement, based on the fluid inclusion temperatures in quartz overgrowth which is approaching the bottom-hole temperatures. The duration of quartz cement after oil emplacement depends upon the saturation of porewater and the distribution of pore water film and the property of water-wet or oil-wet of the reactants. The leaching of K-feldspar by meteoric water requires pore water flow to move the released potassium and sodium and silica out the solution, which suggests the mechanism does not appear to be a major source of silica for quartz cementation. The quartz cementation coincidence with the compaction and pressure solution suggests the major source of silica. The alteration of feldspar by illitization of kaolinite may serve as another important source of silica at deep burial depth. External sources are not need to call on for illustrating the quartz cementation, because there is no evidences for large scale convection of pore water flow occurred in the burial history of reservoir sandstones of middle Jurassic in the North Sea.

Key words quartz cementation reservoir sandstones North Sea

Biography Shao-nan Zhang Male Was born in 1957.10 Professor Petroleum geology

CLC number P618.130.2⁺1 **Document code** A

INTRODUCTION

Since considerable interest and discussion has occurred concerning the duration and sources of silica for quartz cement and their relative importance, the time and depth of cementation of sands, the pathways and sources of water that transports the silica to the site of cementation, reasons for quartz precipitation, that would be useful in understanding diagenetic process in sandstones, including the ability to predict the distribution of porosity in the subsurface. At least 23 possible sources of silica for cement have been proposed (McBride, 1989). No definitive conclusions, however, have been reached on the relative importance of 23 hypotheses. Predicting porosity trends, both on regional and on reservoir scales, recently has become more important as exploration in many basins focuses on deeper reservoirs. Therefore, one must understand the processes controlling quartz dissolution and precipitation. Identifying the sources of silica

that contribute to quartz cementation during diagenesis is the main problem. The duration of quartz cementation relative to temperature and burial depth also is important in terms of predicting porosity loss as a function of progressive burial. All most authors recognize that silica for quartz cementation could be derived from more than one source. Because of the water volume problem, quartz cement in sandstones may be derived from several internal source (Bjørlykke and Egeberg, 1993). In this paper, the duration of quartz cementation and main sources of silica for quartz cement have been discussed and main mechanism of quartz cementation has been proposed.

DURATION OF QUARTZ CEMENTATION

The timing and duration of quartz cement have been studied for predicting the porosity development in reservoir sandstones. Because of quartz cement is chemically very pure and does not contain tracers that

might provide information on the source of the silica or that might allow radiometric dating. The isotopic data of quartz cement can be obtained, but all current techniques require several milligram of sample which is very difficult to get the pure authigenic quartz even using the dental drill, although the laser probe is provided for this kind of usage, which is still not a popular technique. The physical and chemical properties of quartz cement and detrital quartz grains are so similar that it is impossible to isolate a pure sample using physical and chemical methods. Although the method has been used to date the time of authigenic quartz precipitation by means of Electricity Spin Resonance, it is only applied in the sediments younger than Cretaceous ages. The ambient radiogenic matters (Shaonan Zhang, 1994) influence the precision of ESR data. Grant & Oxtoby (1992) pointed out that quartz cementation appears to have taken place over a geologically short period of time in the recent past (less 5 Ma), based upon the studies of fluid inclusion of quartz overgrowth. They found that samples from deeper wells do not give the lower temperatures obtained from the shallower samples in Haltenbanken, which have been interpreted as re-setting by Osborne and Haszeldine (1993). Fluid inclusion in soft minerals such as barite and calcite may stretch if they are heated to temperatures above their entrapment temperatures due to buildup of high internal pressures in the inclusions (Ulrich and Bodnar, 1988; Prezbindowski and Larese, 1987). Experimental studies indicate that aqueous inclusions in quartz may also stretch if heated to sufficiently high temperatures (Bodnar et al., 1989). There are two different ways to attribute to the temperature resetting (1) plastic deformation or stretching; (2) brittle deformation or decrepitation. According to the experiment, internal pressures will not be generated as higher as more than 2500 bar within the realm of burial diagenesis and so decrepitation is an unlikely mechanism for the resetting of fluid inclusions in quartz cements (Osborne and Haszeldine, 1993). The exact process of inclusion resetting is still unknown. Osborne and Haszeldine's (1993) main reason for claiming that homoge-

nization temperatures are resetting is a correlation between homogenization temperatures and present temperature for aqueous inclusion in quartz cement and usually an asymmetry present in the inclusion distribution pattern. The distribution pattern may show the temperatures of quartz overgrowth during progressing burial and the major stage of silica supply at certain depths. The correlation may, however, be explained by quartz precipitation rates increasing dramatically as a function of temperature (Murphy et al., 1989) and that inclusions therefore require much longer times to form at low temperatures (Walderhaug, 1994). The abundance of homogenization temperatures below 100°C or near absence of homogenization temperatures below 100°C is not a result of quartz cementation having started at higher temperatures, but may be a result of inclusions not having had time to form below 100°C. When a set of sandstones of the same age are now at different temperatures, it is not unlikely that the hottest and deepest sandstones have passed most quickly through the quartz cementation window and therefore lack inclusions formed at low temperatures, whereas the coldest sandstones probably have spent longer times in low temperature part of quartz cementation window and therefore contain inclusions formed at lower temperatures (Walderhaug, 1994). The secondary inclusions trapped along healed microfractures and cross-cutting the grain and the overgrowth must show the higher mean homogenization temperatures, but all the homogenization temperatures show a trend of gradually increasing with depth and often overlapping present day formation temperatures (Fig. 1). The homogenization temperatures in many sandstones are relatively limited within a narrow range, so that Robinson and Gluyas (1992) suggested that quartz overgrowth precipitated during discrete, geologically rapid events. This is because that most inclusions are concentrated in narrow zone within 25 μm of the framework grain-overgrowth boundary formed during early stage of overgrowth which is preferentially studied, the temperature ranges thus apply only to those early stages, and not to later developing cement

in which inclusions are rare. Based on temperature history curves, Walderhaug (1994) estimates that quartz overgrowth has occurred over periods ranging up to several tens of millions of years and was not restricted to within the last five years as proposed by Grant and Oxtoby (1992).

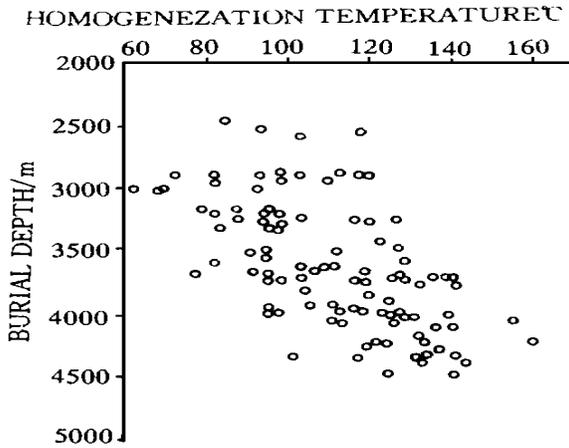


Fig 1 Distribution of homogenization temperatures of fluid in clusions in quartz overgrowth with burial depth in northern North Sea

The other indirect dating the time of quartz overgrowth is the method of K—Ar dating illite. Robinson and Gluyas (1992) using the illite potassium—argon data suggest a maximum age of about 60—70 Ma for quartz overgrowth, based on the interpretation of quartz overgrowth and illite as having grown over approximately the same period. Diagenetic illite is temperature dependent, because very little authigenic illite has been found in the burial depth shallower than 1800 m. High concentrations of illite are only found in deeper burial depths. The dating of illite presents not only the onset of illite but also the beginning of quartz cementation. Two major problems, however, potentially exist with this approach of equating different grain sizes with different ages of illite growth. It is very difficult to monitor small degrees of detrital contaminant. The process of illitization has been influenced by several factors as discussed by Björlykke et al. (1992). Authigenic illite forms primarily by dissolution of kaolinite and K—feldspar in the Brent Group, where the K—feldspar concentration is very low, kaolinite is stable and illitization

has not taken place even at higher temperatures of about 150~160°C (LΦnΦy et al., 1986). In the absence of K—feldspar, however, kaolinite is still stable to much higher temperatures and the abundance of illite much reduced. Illitization seems thus to depend upon the available source of K⁺ and images a rather closed diagenetic system where K⁺ is not supplied from source more distant than a few meters. This will limit the use of dating illite, which is thought to be correspond with the precipitation of quartz overgrowth.

The diagenetic processes are generally thought to be stopped by the emplacement of oil and gas, but the highest homogenization temperatures for inclusions in quartz overgrowth given by Walderhaug (1994) are approximately equal to or a few degree above or below present formation temperature which suggest that quartz overgrowth has continued after hydrocarbon emplacement. Since the oil and gas occupied the pore space and expelled pore water, the migration of silica may only take place by diffusion throughout the water film from sites of dissolution to the sites of precipitation. In the oil zone, however, if the saturation of water is enough for the diffusion of silica, it should result in the overgrowth of quartz, but diffusion of silica depends probably on the distribution of kaolinite and K—feldspar and also the relationship between the contact of kaolinite and K—feldspar as shown in Fig. 2. In Fig. 2a, the quartz and K—feldspar and kaolinite are included in the same water film, therefore, K—feldspar and kaolinite reaction is kinetically controlled at a high temperature, as the result of product, illitization and quartz overgrowth will continually occur. The porosity will be reduced by quartz overgrowth and permeability is decreased dramatically by the onward of illitization. The quartz overgrowth will not be ceased by oil emplacement in this case. If the water saturation is pretty low as shown in Fig. 2b, the water films of grains are separated by oil, quartz and K—feldspar and kaolinite are isolated respectively, or quartz, kaolinite and K—feldspar were wetted by hydrocarbon, no illitization occurs and quartz overgrowth stopped by the oil emplacement. How ev-

er, the quantitative evidence is absent for explaining the importance of influence of hydrocarbon emplacement on the quartz overgrowth and the quality of reservoir.

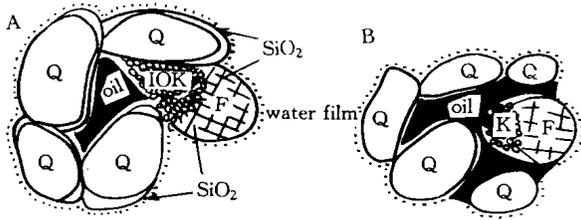


Fig. 2 Conceptual diagram shows the development of quartz overgrowth after oil emplacement. (A) showing the transportation of silica released from K-feldspar caused by the illitization of kaolinite go through the water film and quartz overgrowth continually developed. (B) showing oil separates the connection of water of detrital grains K-feldspar and kaolinite remain sandstones, no illite precipitated. Legend: Q: quartz, F: K-feldspar, K: kaolinite, IOK: illitization of kaolinite.

DISCUSSION

Sources of silica

Many different sources of silica for quartz cementation have been discussed by McBride (1989) and BjØrlykke & Egeberg (1993). Because the difficulty of identifying the source of silica that contribute to the quartz cementation during diagenesis, most authors recognize the likelihood that silica in quartz cement was derived from more than one source, but many interpret a particular source for a given formation to have been dominant. The sources of silica can be classified into two major category: (1): internal sources and (2): external sources. The external sources of silica may include A: hydrothermal solution; B: organic acid solution; C: clay mineral transformation in thick mudstones; D: meteoric fluid flow. The internal sources may include E: compaction and pressure solution; F: dissolution of amorphous silica; G: alteration of K-feldspar and kaolinite by illitization.

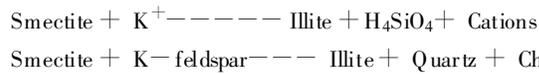
External sources

A: hydrothermal solution has been proposed by Jour-

dan et al. (1987) and Liewig et al. (1987) for fluid flow convection which provides the cations and silica to the sites of precipitation of diagenetic minerals. If hydrothermal solution were responsible for quartz cementation, it seems to reasonable to expect that fluid inclusions in quartz overgrowths would commonly have homogenization temperatures above present formation temperatures in sandstones where hydrothermal activity is not taking place at present (Walderhaug, 1994). The homogenization temperatures are equal to or approach the present formation temperatures, this suggests that hydrothermal solution did not take place in the diagenetic development of reservoir sandstones. If hot water were introduced along faults and fractures in early Tertiary time (Jourdan et al., 1987; Liewig et al., 1987), the flow rate should have been expected to be reduced by the overlying clay-rich Cretaceous and lower Tertiary sediments. B: organic acid solution is effective in dissolving silicate minerals and silicate rock fragments especially feldspars (Huang and Keller 1970; Surdam et al., 1984). The silica may released by destruction of silica-bearing organic complexes, which suggests that silica was dissolved by organic acid from the sites closed to the place of source rock or along the pass way of organic acid migration, it is thought more corrosive than carbonic acid to be as an agent for dissolution of detrital fragments (Meshri, 1986). The organic acid model is, to a large extent, based on evidence obtained from laboratory experiments. The mass balance calculations (Giles and Marshall, 1986) and the relative timing of acid producing reactions and secondary porosity generation (Lundegard and Land, 1986) have been questioned/ Misinterpretation of the timing and depth of extensive feldspar dissolution can be the result of the largely unsubstantiated assumption that "delicate" remnants of the original grains cannot survive significant burial. Thus much of the "late" dissolution of aluminosilicate minerals may have formed in the shallow subsurface, and there is no reason to invoke organic acids as a leaching medium (Bloch, 1994). In North Sea region, BjØrlykke and others (1992) indicated that the dissolution of

feldspar is not related to the generation of acids in source rocks, it is difficult to explain why sandstone so closely associated with mature source rocks are not affected by this process, such as the Fulmar Sandstone and the Claymore Formation showing little leaching of feldspar which is overlaid by source rocks. The practical applications of the hypothesis of organic acid leaching are not clear. The supply of silica for quartz overgrowth could not be attributed to the organic acid solution.

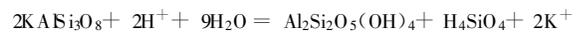
C: clay mineral transformation in thick mudstone is considerably thought to be a important source of silica supply. The following reactions have been used to illustrate the process of silica released from the clay mineral conversion:



Based on the reactions, Leder and Park (1986) calculated that shale 1 km thick can release sufficient silica to completely cement an overlying sandstone bed 100 m thick. It has little doubt that large amount of silica can be generated during the transformation of clay minerals. The transformation of clay minerals is temperature dependence, the volume of pore water, however, is not enough to carry significant fluid for silica migrating out of the shale at such depth equivalent to the high temperatures, because the shales have continuously been compacted and dewatered to a large extent. The silica, therefore, may consume within shales. Compaction flow or diffusion could only transport the silica released from transformation of clay minerals. The porewater flow generated by compaction is limited, based on the calculation of porewater expulsion (BjØrlykke and Aagaard, 1992). Yeh and Savin (1977) found evidence suggesting that the shale acts as a sink for released silica. The permeability of shales at certain depth is too low to exposing pore water outside at a high rate, the cations and silica do not freely pass through from the site released to the position of precipitation. The rate of compaction-driven flow is on average smaller than the subsidence rate (BjØrlykke, 1994), the silica can not, significantly, get the point of sandstone as quartz

overgrowth. The diffusion of silica is influenced by temperature, concentration gradient and diffusion coefficient of matrix (BjØrlykke, 1994) and thought to be available in a short distance and small scale.

D: meteoric fluid flow has a great potential to dissolve silicates in active vadose zone and influenced as deep as 2~3 km (Bethke et al., 1988). The dissolution of feldspar by meteoric water leaching has been invoked as an important source of silica (Blatt, 1979), which is normally supersaturated with respect to quartz. The early quartz cement may come from the dissolution of unstable rock fragments and feldspar. The distribution of quartz cement indicates the precipitation of silica is prevented from lower temperatures at shallow depth. kaolinite precipitation from the dissolution of K-feldspar releases excess silica in pore fluid, the reaction has been described as following:



It is clear that kaolinite precipitation requires K^+ and H_4SiO_4 to be moved out of the site in order to keep the reaction going, therefore, large amount of meteoric water is needed. If K^+ is carried out, it is difficult to understand why the silica is remained in sandstones. BjØrlykke and Egeberg (1993) point out that if silica were allowed to build up in the pore water, smectite would precipitate rather than kaolinite. There is no evidence showing that smectite exists in shallow burial sandstones, this suggests that the silica released is migrated along with the meteoric water from the site of K-feldspar dissolution. One may argue that there exists the difference of migrating rate between K^+ and H_4SiO_4 , SiO_2 may exist in sandstones as colloid, therefore, K^+ is transported by meteoric water more faster and easier than colloid, this process is difficult to be known. However, the petrologic studies indicate that minor quartz cement has been found in sandstones at shallow burial depth, suggesting silica and K^+ are removed together by the meteoric pore water flow. Therefore, meteoric fluid flow is favourable to the formation of kaolinite not quartz overgrowth.

Internal source

E: compaction and pressure solution are the most likely source of quartz cement. The sandstones, which are buried at intermediate and deep depth, are undergoing overburden stress, this will increase the solubility of silica at the surface of quartz to quartz contact. The dissolved silica can then precipitate on adjacent quartz surfaces which experience a lower degree of stress (Wilson and Stanton, 1994). The stylolite and microstylolite have been observed in reservoir sandstones in North Sea. Cathodoluminescence images provide directly evidences for stylolite and microstylolite at grain contact (e. g. Harris 1992) and also a good basis for quantifying the amount of pressure solution (Houseknecht, 1988). Stylolite and microstylolite may probably be more abundant in the sandstones which contain mica and clay seams. These materials are thought to be chemical catalyst for pressure solution. The pressure solution is preferentially well developed in very fine and fine grain size sandstones, therefore, the authors indicate that grain pressure solution is size-dependent (Renton et al., 1969; Houseknecht, 1984). Thus, silty or clay size quartz in sandstones may dissolve totally and leave very little trace (BjØrlykke and Egeberg, 1993). Since the significant abundant of quartz cement coincides with the present of stylolite and microstylolite, the compaction and pressure solution may be the major and important source for quartz cementation despite of the difficulties to measure the volume of dissolution along the surface of grain contact and stylolite.

F: dissolution of amorphous silica is an attractive potential source of quartz cement. The amorphous silica is susceptible to dissolution during diagenetic process and is more than an order of magnitude greater than quartz (Siever, 1957). The sandstones deposited in marine environments generally contain a certain amount siliceous biotritus, such as siliceous sponge spicules, radiolaria, and diatom. The composition of most bioclasts is consisted of opal. BjØrlykke and Egeberg (1993) have discussed the stability of opal CT. The opal CT is metastable in pore water fluid at low temperatures (below 70 °C—80 °C). The trans-

formation of opal CT and opal A is a time—temperature function. The opal A is found below 1 000m burial depth, and cristobalite is found at 1 500 m burial depth, these suggest that this kind of silica is metastable and did not dissolve significantly at low temperatures and shallower burial depth, it may indicate that the rate of quartz overgrowth is very much low at the depth. At deeper burial depth (deeper than 2 500 ~ 3 000 m), it may serve as a source of silica for quartz cementation, due to the extensive impurities which is subject to the pressure solution. The chert and volcanic detritus could serve as a source of silica when they are dissolved during diagenesis of sandstones. The chert may be metastable as opal A and opal CT at shallow burial depth, because of the pore water is supersaturated with respect to quartz (BjØrlykke and Egeberg 1993). The amount of volcanic detritus is minor in sandstones in North Sea, therefore, the significance of silica source is limited.

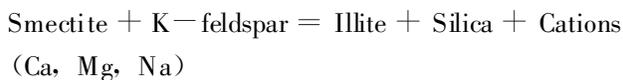
G: alteration of K—feldspar and Kaolinite by illitization has been invoked to produce excess silica (BjØrlykke and Egeberg 1993; BjØrlykke 1994; Harris 1992; BjØrlykke and Aagaard 1992; Siever 1957; Hawkins 1978). Siever (1957) suggested that two moles of silica are released when one mole of K—feldspar altered to kaolinite and made the silica available for quartz overgrowth. McBride (1989) considered, however, that sandstones with abundant quartz cement have or had few feldspars, and most arkoses have more clay and carbonate cements than quartz cement. It is clear that feldspar may not be the major source of quartz cement but it does act as important one of the source of silica during diagenesis of sandstones, especially at deeper burial depth. K—feldspar is unstable at temperatures higher than 130 °C with the presence of kaolinite, the alteration of K—feldspar and kaolinite by illitization will occur, as the following reaction shows:



K—feldspar kaolinite illite

This reaction is kinetically proceeded by illite development. This diagenetic event occurred at high temperatures and durates up to present day by the K—Ar

data. However, this reaction depends on the amount of either K—feldspar or kaolinite available, if kaolinite is in shortage for the reaction, K—feldspar will remain in sandstone, the same does the K—feldspar, that will cease the quartz cementation, the amount of silica supply by this mechanisms is limited. The petrologic studies show that the most or all of kaolinite in sandstones is altered by illitization and few K—feldspar is left in the fluvial and shallow marine sandstones in North Sea, exceptionally turbidites, it may illustrate the occurrence of few feldspars and more clay minerals in most sandstones. It is very difficult to quantitatively measure the amount of silica released by alteration of K—feldspar and kaolinite. The smectite will consume K—feldspar by illitization to produce excess silica where kaolinite is absent as described as following:



This reaction may also serve as a source for calcite and dolomite precipitation at deeper burial depth during late diagenesis.

In summary of silica source, it is very difficult to stop the dispute about the quartz cementation in sandstones explained using single mechanisms. The amount of quartz cement increasing with the burial depth suggests that quartz cementation is temperature—dependent. The sources of silica may not have only one, the major source of silica may be compaction and pressure solution, but the alteration of K—feldspars and kaolinite and transformation of smectite to illite may contribute a lot as well. The explanation for quartz cementation in middle Jurassic sandstones in the North Sea should combine the three mechanisms which come from internal source. The external sources are not necessary to call on for the illustration of quartz overgrowth, the transportation of large volumes of silica from a long distance in deep subsurface is theoretically difficult to explain (BjØrlykke et al., 1992). The distribution of salinity in pore waters in the North Sea suggests that there is no large scale vertical mixing of pore fluids (Gran et al., 1992).

CONCLUSIONS

Quartz cement is one of the two most abundant cements in sandstones and main factor for porosity loss. The timing and duration of quartz cement have been mainly inferred from diagenetic texture, relationship between pore filling minerals, fluid inclusions and isotopic data. The duration for quartz cement, from the onset, trends to continue after oil emplacement until the porosity completely lost, although the rate of quartz precipitation has been retarded.

The source of silica that forms overgrowth is from more than one diagenetic processes. Minor amount of quartz cement (less than 5%) at shallow depth may be count for the internal source of amorphous silica and opal CT. Released silica as a result of K—feldspar leaching by meteoric water flushing did not contribute a significant volume of quartz cement. The compaction and pressure solution are primarily the major source of silica supply within the sandstones. Alteration of K—feldspar and kaolinite by illitization may provide additional quartz cement especially at deep burial depth. Diffusion played a very important role in quartz overgrowth in the small scale as well as after the emplacement of oil.

ACKNOWLEDGEMENTS

Shaonan Zhang would give many thanks to the department of geology at University of Oslo, which provides the working conditions for my post doctor research so that this paper can be finished.

REFERENCE

- 1 Bethke C M, Harrison W J, Upson C, Altaner S P. Supercomputer analysis of sedimentary basins[J]. *Science*, 1988, 239: 233~237
- 2 BjØrlykke K. Fluid—flow processes and diagenesis in sedimentary basins[A]. In: Parnell J, ed. *Geofluid: Origin, migration and evolution of fluids in sedimentary basins*[C]. Geological Society Special Publication, 78, 1994, 127~140
- 3 BjØrlykke K, Egeberg P K. Quartz cementation in sedimentary basins[J]. *American Association of Petroleum Geologists Bulletin*, 1993, 77: 1538~1548
- 4 BjØrlykke K, Aagaard P. Clay minerals in North Sea sandstones [A]. In: Houseknecht D W, Pittman E D, eds. *Origin, diagenesis, and petrophysics of clay minerals in sandstones*[C]. SEPM Special Publication 47, 1992, 65~80
- 5 BjØrlykke K, Nedkvitne T, Ramm M, Saigal G C. Diagenetic processes in the Brent Group (Middle Jurassic) reservoirs of the North Sea: an overview[A]. In: Morton A C, *et al* eds. *Geology of the Brent Group*[C]. Geological Society Special Publication, 61, 1992.

- 263~287
- 6 Blatt H. Diagenetic processes in sandstones[C]. SEPM Special Publication 26, 1979, 141~157
 - 7 Bloch S. Effect of detrital mineral composition on reservoir quality [A]. In: Wilson M D, ed. Reservoir quality assessment and prediction in clastic rocks[C]. SEPM Short course 30, 1994, 161~182
 - 8 Bodnar R J, Binns P R, Hall D L. Synthetic fluid inclusions—VI. Quantitative evaluation of the decrepitation behavior of fluid inclusions in quartz at one atmosphere confining pressure[J]. Journal of Metamorphic Geology, 1989, 7: 229~242
 - 9 Giles M R, Marshall J D. Constraints on the development of secondary porosity in the subsurface: reevaluation of processes[J]. Marine and Petroleum Geology, 1986, 3: 243~255
 - 10 Gran K, Bjørlykke K, Aagaard P. Fluid salinity and dynamics in the North sea and Haldenbanken basins derived from well log data [A]. In: Hurst A, *et al.*, eds. Geological applications of wireline logs II[C]. Geological Society Special Publication 65, 1992, 327~338
 - 11 Grant S M, Oxtoby N H. The timing of quartz cementation in Mesozoic sandstones from Haldenbanken, offshore mid-Norway: fluid inclusion evidence[J]. Journal of the Geological Society, London, 1992, 149: 479~482
 - 12 Harris N B. Burial diagenesis of Brent sandstones: a study of Staffjord, Hutton and Lyell fields[A]. In: Morton A C, *et al.*, eds. Geology of Brent Group[C]. Geological Society Special Publication, 61, 1992, 351~375
 - 13 Hawkins P J. Relationship between diagenesis porosity reduction and oil emplacement in late Carboniferous sandstone reservoirs, Bothamsall oil field, E. Midlands[J]. Journal of geological society of London, 1978, 135: 7~24
 - 14 Houseknecht D W. Influence of grain size and temperature on intergranular pressure solution, quartz cementation, and porosity in quartzose sandstone[J]. Journal of sedimentary petrology, 1984, 54: 348~361
 - 15 Houseknecht D W. Intergranular pressure solution in four quartzose sandstones[J]. Journal of sedimentary petrology, 1988, 58: 228~246
 - 16 Huang W H, Keller D G. Dissolution of rock-forming silicate minerals in organic acids: Simulated first-stage weathering of fresh mineral surfaces[J]. American Mineralogist, 1979, 55: 2076~2094
 - 17 Jourdan A, Thomas M, Brevart O, *et al.* Diagenesis as the control of Brent sandstone reservoir properties in the Greater Alwyn area (East Shetland Basin)[A]. In: Brooks J, Glennie K, eds. Petroleum geology of north west Europe[C]. Graham and Trotman, London, 1987, 951~961
 - 18 Leder F, Park W C. Porosity reduction in sandstone by quartz overgrowth[J]. American Association of Petroleum Geologists Bulletin, 1986, 70: 1713~1728
 - 19 Liewig N, Clauer N, Sommer F. Rb—Sr and K—Ar dating of Clay diagenesis in Jurassic sandstone oil reservoir, North Sea[J]. American Association of Petroleum Geologists Bulletin, 1987, 71: 1467~1474
 - 20 Lundegard P D, Land L S. Carbon dioxide and organic acids: their role in porosity enhancement and cementation, Palaeocene of the Texas Gulf Coast[A]. In: Gautier D L, ed. Roles of organic matter in sediment diagenesis[C]. SEPM Special Publication 38, 1986, 129~146
 - 21 Lønne A, Akselsen J, Rønning K. Diagenesis of a deeply buried sandstone reservoir; Hild Field, Northern North Sea[J]. Clay Minerals, 1986, 21: 497~511
 - 22 McBride E F. Quartz cementation in sandstones: a review[J]. Earth—Science Review, 1989, 26: 69~112
 - 23 Meshni I D. On the reactivity of carbonic and organic acids and generation of secondary porosity[A]. In: Gautier D L, ed. Roles of organic matter in sediment diagenesis[C]. SEPM Special Publication 38, 1986, 123~128
 - 24 Murphy W M, Oelkers E H, Lichtner P C. Surface reaction versus diffusion control of mineral dissolution and growth rates in geochemical processes[J]. Chemical Geology, 1989, 78: 357~380
 - 25 Osborn M, Haszeldine S. Evidence for resetting of fluid inclusion temperatures from quartz cements in oil fields[J]. Marine and Petroleum Geology, 1993, 10: 271~278
 - 26 Prezbindowski D R, Laese R E. Experimental stretching of fluid inclusions in calcite—implications for diagenetic studies[J]. Geology, 1987, 15: 333~336
 - 27 Renton J J, Heald M T, Cecil C B. Experimental investigation of pressure solution of quartz[J]. Journal of sedimentary petrology, 1969, 39: 1107~1117
 - 28 Robinson A, Ghayas J. Model calculations of loss of porosity in sandstones as a result of compaction and quartz cementation[J]. Marine and Petroleum Geology, 1992, 9: 319~323
 - 29 Siever R. Pennsylvanian sandstones of the Eastern Interior Coal Basin[J]. Journal of sedimentary petrology, 1957, 27: 227~250
 - 30 Sipple R F. Sandstone petrology: evidence from luminescence petrography[J]. Journal of Sedimentary Petrology, 1968, 38: 530~554
 - 31 Surdam R C, Boese S W, Crossey L J. The chemistry of secondary porosity[A]. In: McDonald D M, Surdam R C, eds. Clastic diagenesis[C]. American Association of Petroleum Geologists Memoir 37, 1984, 127~149
 - 32 Ulrich M R, Bodnar R J. Systematics of stretching of fluid inclusions II: barite at 1 atm confining pressure[J]. Economic Geology, 1988, 83: 1037~1046
 - 33 Walderhaug O. Temperatures of quartz cementation in Jurassic sandstones from the Norwegian continental shelf—evidence from fluid inclusions[J]. Journal of Sedimentary Research, 1994a, 64: 311~323
 - 34 Wilson M D, Stanton P T. Diagenetic mechanisms of porosity and permeability reduction and enhancement[A]. In: Wilson M D, ed. Reservoir quality assessment and prediction in clastic rocks[C]. SEPM Short course 30, 1994, 59~118
 - 35 Yeh H, Savin S M. Mechanism of burial metamorphism of argillaceous sediments. 3. O— isotope evidence[J]. Geological Society of American Bulletin, 1977, 88: 1321~1330